AUGUSTINUS & BARD

Investigation of Phase Relations in Transformer Circuits

Electrical Engineering

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INVESTIGATION OF PHASE RELATIONS IN TRANSFORMER CIRCUITS

BY

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THESIS

For the Degree of Bachelor of Science
in Electrical Engineering

COLLEGE OF ENGINEERING
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June 1, 1906

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

PAUL AUGUSTINUS and JACOB WILLIAM BARD

ENTITLED INVESTIGATION OF PHASE RELATIONS IN

TRANSFORMER CIRCUITS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Electrical Engineering

Morgan Brooks

HEAD OF DEPARTMENT OF Electrical Engineering

Investigation of the Phase Relations in Transformer Circuits.

Introduction.

In general practice, the phase angle in the secondary of a transformer is assumed to be equal to that of the primary. This, of course, would also mean that the power factor of the two circuits are equal. To investigate the phase relations, therefore, it shall be necessary only to compare the power factors of the two circuits for various conditions.

Method of Conducting Experiments.

In order to magnify the effect, two 7.5 K.W. transformers were connected in cascade as shown in diagram A. To eliminate errors, it was desired to use only one set of instruments for both circuits. The scheme of connections is as follows: (a) is a single phase alternator connected to the secondary (b) of one of the transformers used. The primary (c) of this transformer is then connected to the primary (d) of a similar

transformer, and the secondary (e) of the latter connected to the load. By means of switches (f) and (g), the current of either circuit can be made to pass through the ammeter and wattmeter. To change the instruments over to either side, without disturbing the load, short-circuiting switches (h') and (h") are provided across the switches (f) and (g) respectively. By means of a D.P.D.T. switch, the pressure coil of the wattmeter can be thrown across the terminals of the alternator or across the load. The voltmeter is connected in a manner similar to that used for the pressure coil of the wattmeter.

A set of data was now taken for non-inductive, inductive and capacity loads. From these data, the power factors were calculated, and points plotted, using power factors on load side for abscissas, and power factors on generating side for ordinates. Now, if the power factors on one side were equal to those on the other side of the transformers, all the points plotted would fall on a 45° line. From the average value of these points, for non-inductive

and inductive loads, this was practically found to be true, which conforms with the general assumption. The results obtained from capacity loads, however, showed in behavior a marked deviation from what was expected. It was found that all the power factors on the generating side were greater than those on the load side, so that all the points fell above the 45° line.

It is seen then that under certain conditions, at least, there may be some difference in the phase angles of the two circuits. To verify the results obtained, the investigation was carried still further by comparing a number of curves of currents and pressures, taken simultaneously by means of an oscillograph. Connections for this part of the experiment are shown in diagram B, which is very similar to A. (a) is the alternator, (b) the secondary of one transformer, (c) and (d) the two primaries, while (e) is the secondary connected to the load as shown. (f) and (g) are the oscillators, one being connected so as to give the pressure curve, while the other gives that of the current. D.P.D.T. switches are used to throw either side of the trans-

formers on the oscillators.

In order to obtain the current curves, it was necessary to insert in series with each circuit a non-inductive resistance, across which the current oscillator was connected as shown at (r) and (s). Curves of currents and pressures were then traced for non inductive, inductive and capacity loads. The results obtained were as follows: With non-inductive load, the current on the power side showed a small angle of lag, while on the load side both current and pressure were apparently in phase. Applying inductive load, the phase angle proved to be practically the same in both circuits, which might be predicted from the preceding experiments. The curves obtained when applying capacity loads, however, showed an additional and unexpected peculiarity; for it was found that the current in the power circuit was lagging, while that in the load circuit was leading.

For the preceding experiments, inductive effect was obtained by means of transformers and induction coils, while the capacity effect was produced by means of condensers.

In transmission lines, using substations, the phase angle may be altered by means of over and under exciting the converters. It was therefore desireable to perform a test of this nature. To that end Danville, Urbana and Champaign Railway transmission line was selected for the experiment. On the day of the test, the power was supplied from Champaign only. A 15000 volt line extends from the plant to a substation at St. Joseph, about eleven miles from Champaign. At this point it is stepped down to 350 volts to suit the converters. The instrument at both plant and substation are placed on the low tension side, being consistant with the conditions under which the previous experiments were made.

Men were stationed at each end to take readings of instruments. At a certain prearranged time, readings were started simultaneously, and then taken every thirty seconds, a telephone service being provided in order to begin readings at the same time. During the first twenty-five minutes, the change of excitation was made at St. Joseph only. Starting with a lagging current, the ex-

citation was gradually increased, at regular intervals, until a leading current was obtained. The excitation at St. Joseph was then made normal, while the experiment was performed at Champaign for the following twenty five minutes. A comparison of the data taken at both ends showed a lagging current at Champaign for all phases at St. Joseph, during the first twenty five minutes, while a leading current was obtained at St. Joseph for all phases at Champaign, throughout the last twenty five minutes.

These last data taken on the transmission line are of interest, as they corroborate the previous results obtained. However, due to rapid fluctuations of load, accurate numerical values could not be obtained for the comparison of the phase angles.

From the above experiments, it appears that under certain conditions, there may be an appreciable difference in phase angles of transformer circuits. Under such conditions, this would lead to an error in switchboard instruments, where a transformer system is used. The investigation, as far as carried, does

not determine the numerical values of such instrumental errors, but it may serve as a basis for further and more comprehensive experiments in that line.

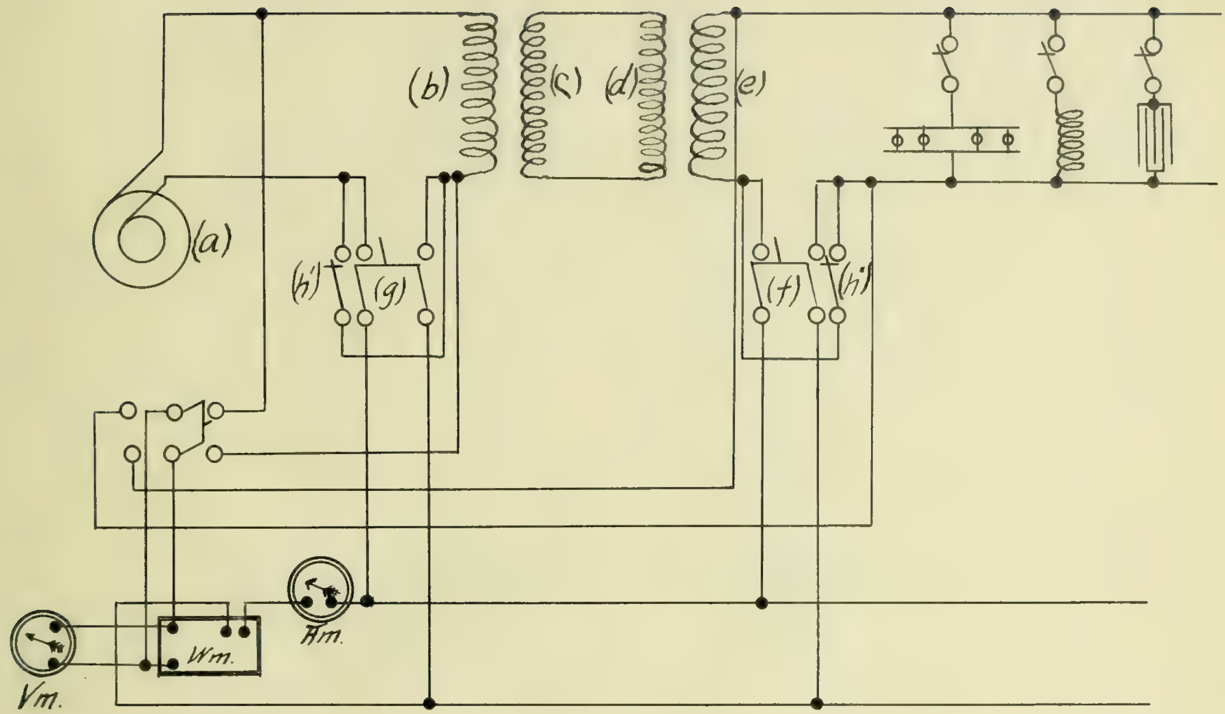


Diagram A

Arrangement of switches & instruments

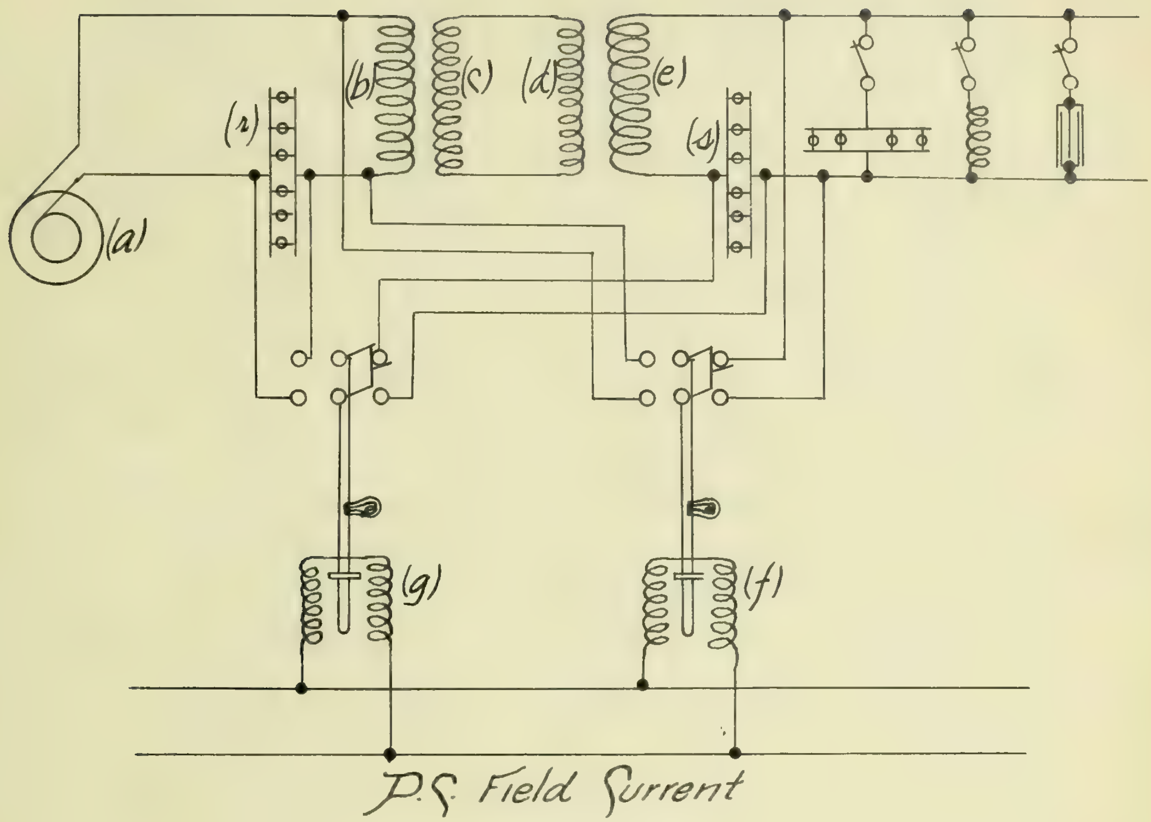


Diagram B.

Arrangement of switches & oscillograph

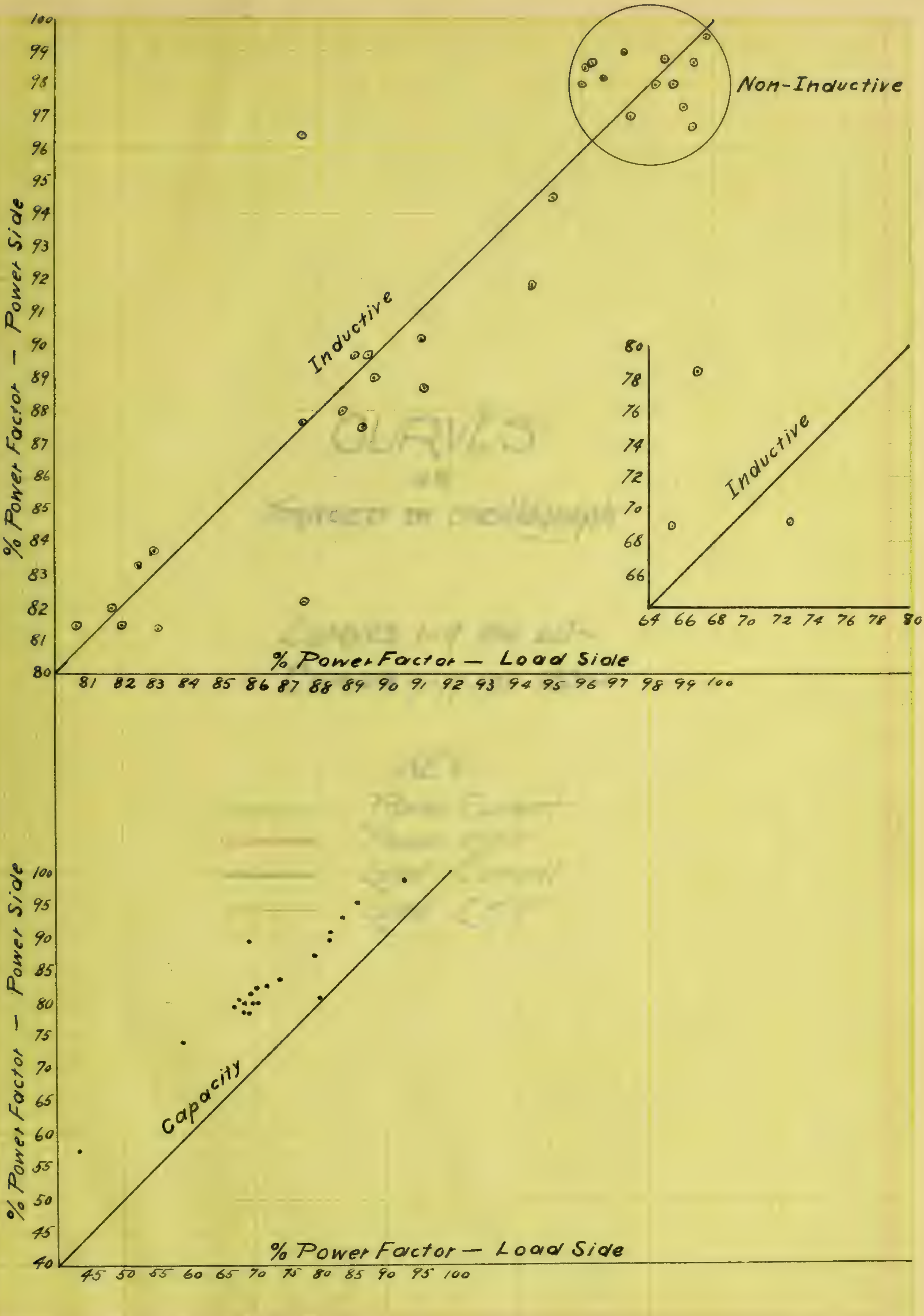
Power Side Non-Inductive Load

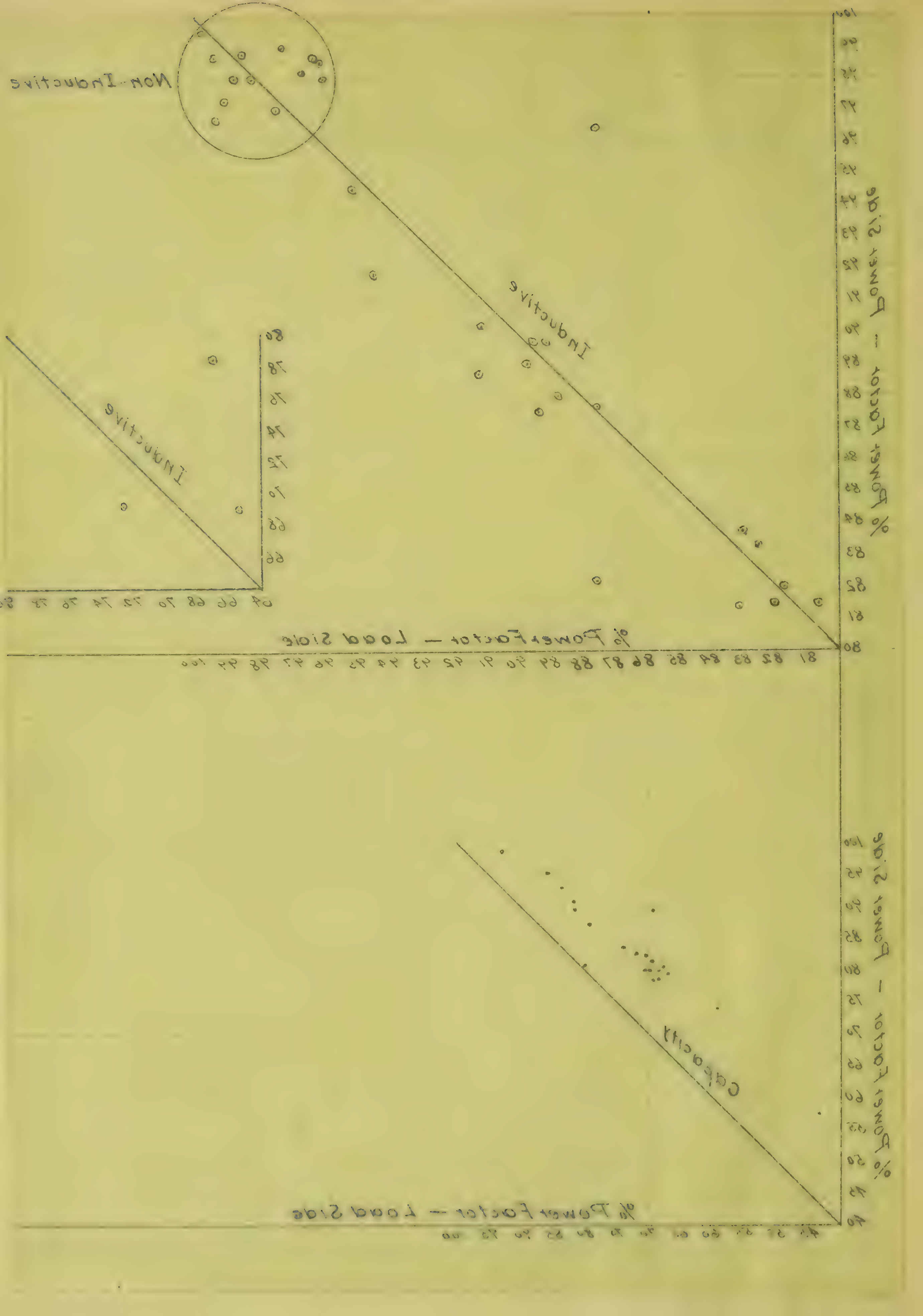
W	E	I	% P.F.		W	E	I	% P.F.
1516	110.4	15.3	89.7		1172	108.1	10.75	
1984	109.9	18.75	96.4		1527	107.1	16.3	87.5
2398	109.8	22.25	98.2		1990	106.5	19.3	96.8
2858	109.1	26.5	98.8		2415	104.3	23.5	98.5
3228	109.1	30.8	97.1		2858	104.3	27.3	
3685	108.9	34.6	98.0		3175	103.5	32.0	96.
4050	108.5	38.6	97.		3540	102.4	35.5	97.5
4375	108.25	41.5	97.5		3775	101.0	36.5	
4800	108.25	44.8	99.		4100	100.2	42.0	97.3
5320	107.8	50.2	98.5		4545	101.2	46.8	96.1
5625	107.0	54.4	96.7		4880	98.4	50.0	99.4
5980	106.7	57.0	97.3		5120	96.85	53.4	99.1
6190	105.7	59.5	98.5		5250	94.7	56.0	99.8
6260	103.7	61.25	98.7		5320	93.0	57.6	99.4
6500	103.1	64.25	98.		5550	91.9	61.25	98.8
6740	102.0	67.3	98.		5670	90.7	63.7	98.2
6810	100.0	69.0	98.7		5730	89.2	66.75	96.3

Power Side					Inductive Load			
W	E	I	% P.F.		W	E	I	% P.F.
2845	108.0	31.3	83.3		2360	104.1	27.5	82.5
3300	109.75	37.0	81.4		2860	103.0	33.5	83.1
3655	109.25	40.7	82.2		3170	101.9	38.25	87.5
4120	107.8	46.7	82.		3495	97.9	44.0	81.7
4120	105.3	48.0	81.7		4145	95.3	45.5	95.5
4450	108.3	50.5	81.5		3760	97.9	47.8	80.6
5130	108.0	58.3	81.5		4370	96.2	56.0	82.
3420	110.25	35.0	87.7		2970	103.0	32.5	87.5
3725	109.75	38.3	88.7		3300	102.0	35.5	91.2
5930	107.5	61.5	89.7		5020	94.3	59.5	89.5
5670	108.5	59.5	88.-		4830	95.6	57.0	88.7
4780	109.75	48.5	89.7		4020	98.3	46.0	89.1
3830	109.75	40.0	87.5		3330	102.25	36.5	89.3
3000	111.0	39.2	69.		2450	103.25	36.2	65.5
3370	110.25	43.5	69.2		2880	102.6	38.75	72.6
3720	109.25	43.5	78.4		3160	100.25	40.75	67.
4360	108.7	48.0	83.8		3730	97.8	45.5	83.
5210	109.25	53.75	88.8		4400	96.3	51.4	89.7
5780	108.7	59.0	90.2		4910	95.3	56.6	91.1
6320	108.0	63.75	91.8		5500	94.3	61.7	94.5
6970	108.0	68.25	94.5		5910	92.7	67.0	95.1

Power Side Capacity Load

W	E	I	% P.F.		W	E	I	% P.F.
6000	108.1	63.7	87.2		5090	101.0	63.7	79.2
4760	110.3	54.5	78.3		3970	104.6	54.8	69.3
4750	106.9	49.7	89.5		4100	104.0	49.0	81.5
3790	107.6	39.3	89.6		3270	104.6	44.8	69.2
3870	107.4	44.8	80.5		3240	104.75	38.7	80.0
4900	105.8	57.0	81.4		4060	103.75	56.5	69.5
4720	107.2	54.6	80.5		3920	105.3	55.0	67.7
4210	107.2	49.5	79.5		3520	105.3	50.0	67.0
3920	107.8	45.5	80.		3270	105.3	45.5	68.2
3475	108.3	40.2	78.6		2930	106.25	40.2	68.7
3300	108.9	37.5	80.		2830	107.2	37.5	70.5
3000	108.5	34.5	80.		2510	106.25	33.8	70.
2500	109	27.7	82.9		2120	107.2	27.5	72.
2190	109.75	24.3	82.2		1800	108.2	23.7	70.2
1760	110.0	19.8	80.		1450	108.7	19.5	68.5
2085	109.75	33.0	57.5		1600	109.6	33.7	43.3
2935	108.1	36.7	74.		2445	106.7	36.8	59.
3835	107.6	42.6	83.7		3290	105.4	42.2	73.9
4600	106.8	47.5	90.8		3960	103.7	46.8	81.6
4940	106.2	50.1	93.		426	102.7	49.7	83.5
5335	105.7	53.0	95.3		4582	101.8	52.5	85.8
6235	104.5	60.7	98.5		5420	98.0	60.0	92.5


% Power Factor — Power Side
100 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80
Non-Inductive
Inductive
% Power Factor — Load Side
81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
80 78 76 74 72 70 68 66
Inductive
64 66 68 70 72 74 76 78 80
% Power Factor — Power Side
100 95 90 85 80 75 70 65 60 55 50 45 40
Capacity
% Power Factor — Load Side
45 50 55 60 65 70 75 80 85 90 95 100



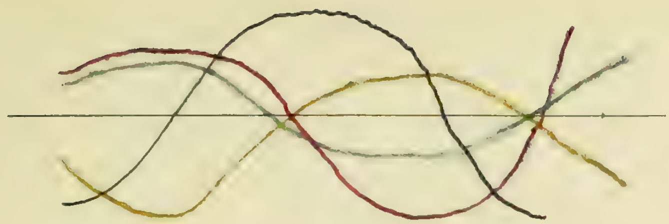
Non-Inductive
Inductive
Inductive
% Power Factor — Power Side
% Power Factor — Load Side
Capacity
% Power Factor — Power Side
% Power Factor — Load Side

CURVES
as
TRACED BY oscillograph

CURVES 1-9 FOR 60~
CURVES 9-17 For 120~

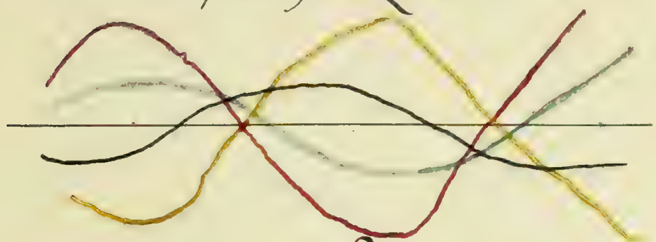
KEY

Power Current
Power E.M.F.
Load Current
Load E.M.F.



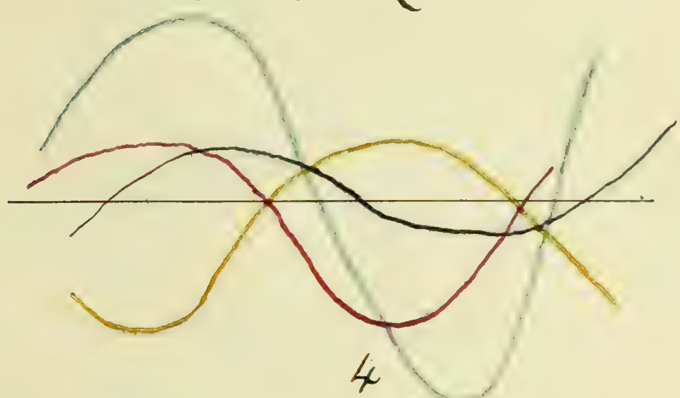
1

Capacity Load



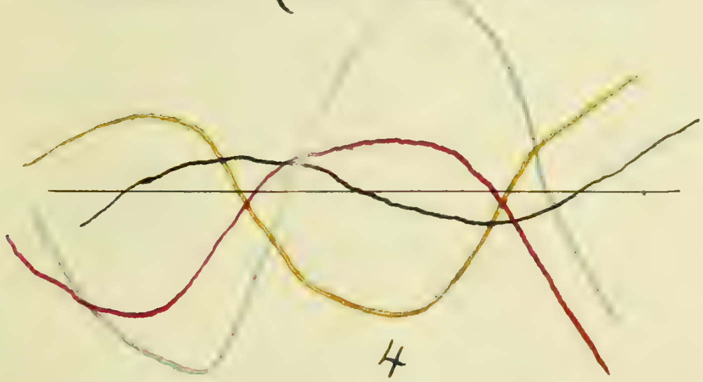
2

Capacity Load



4

Inductive Load with Iron Core



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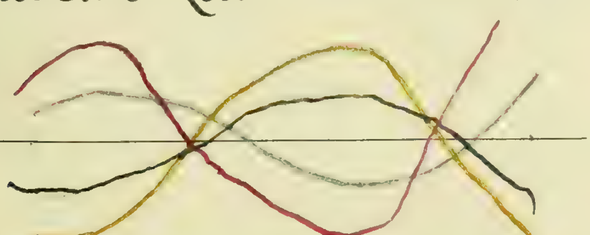
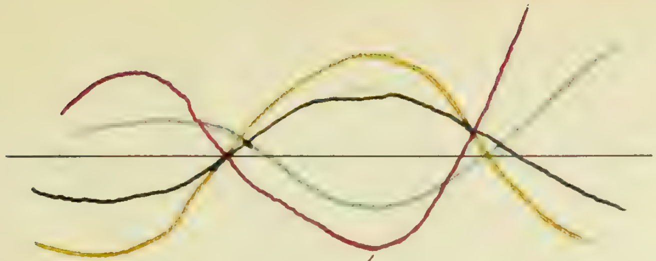
Inductive Load with Iron Core



5

Inductive Load with Air Core



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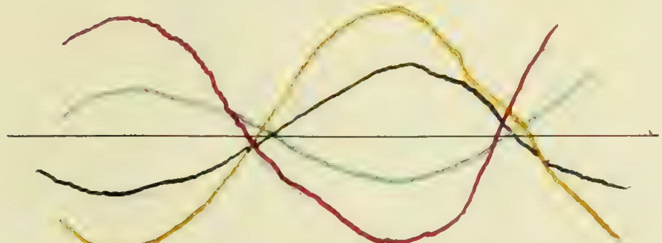
Inductive Load with Air Core



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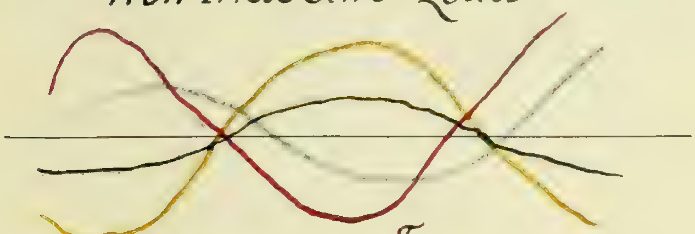
Non-Inductive Load



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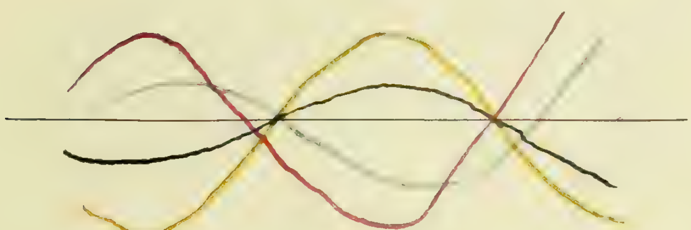
Non-Inductive Load



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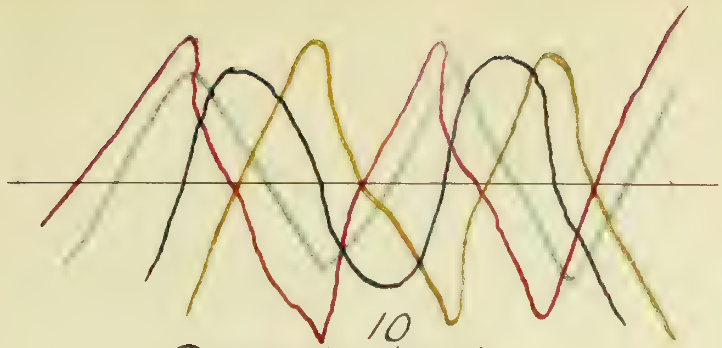
Non-Inductive Load



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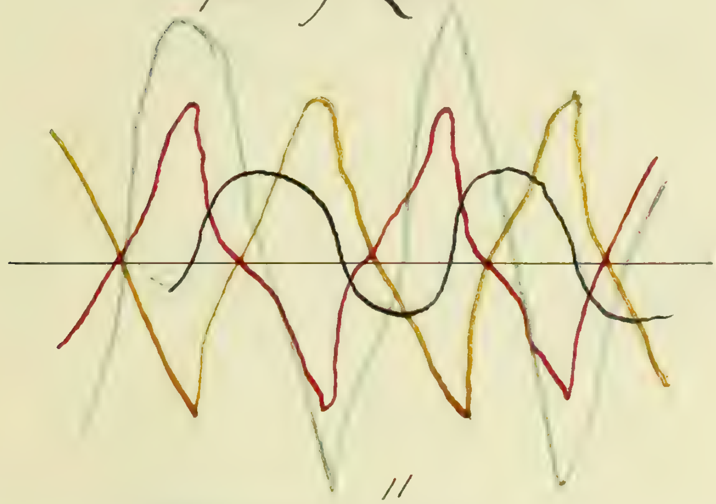
Capacity Load



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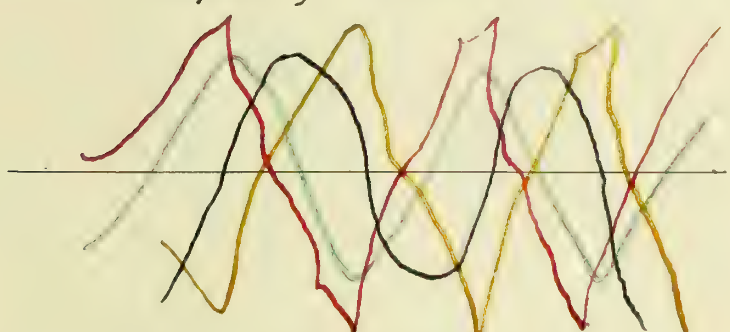
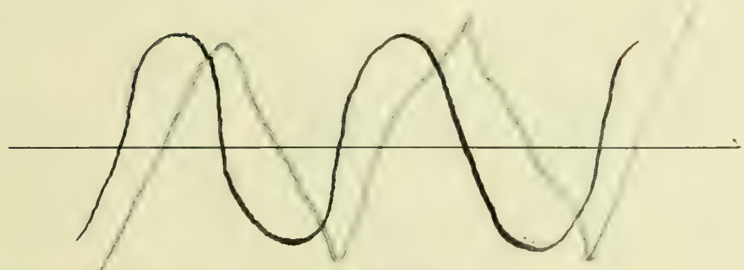
Capacity Load



12
Capacity Load



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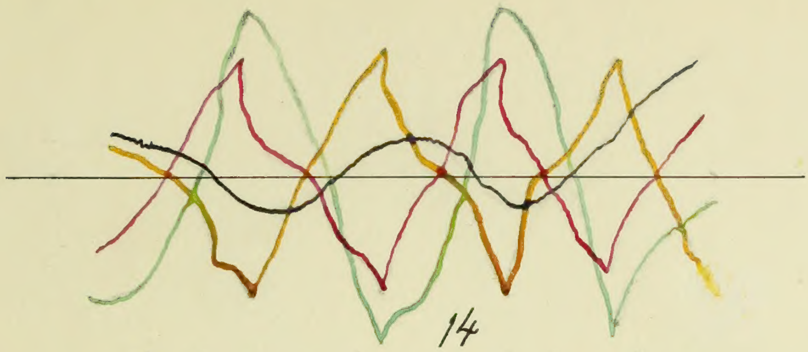
Currents For Capacity Load



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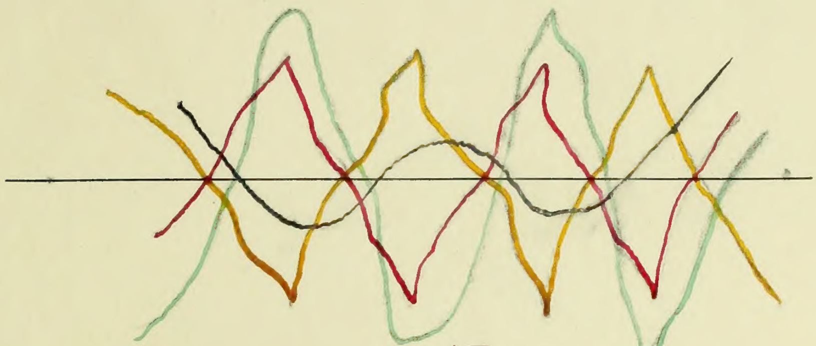
Inductive Load with Iron Core



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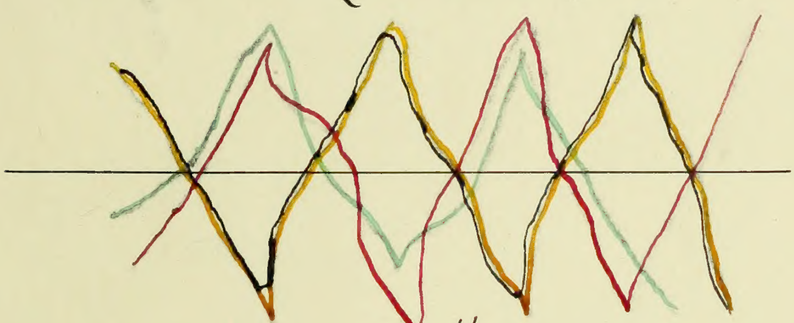
Inductive Load with Iron Core



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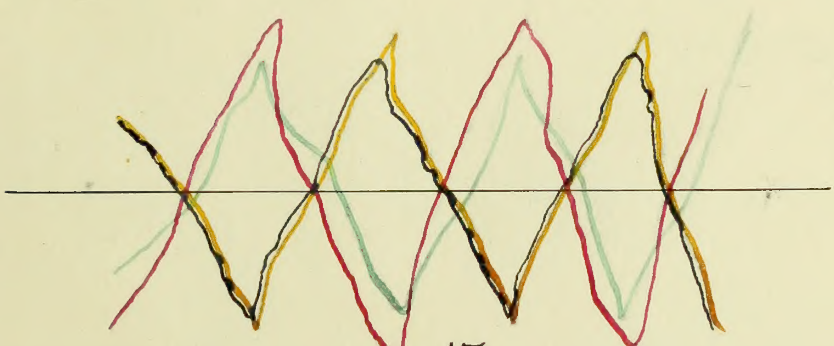
Non-Inductive Load



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Non-Inductive Load